one or more of them come in contact with the upper portion of the female cell they blend with it and their contents are absorbed and fertilization is effected. Soon a rapid growth of filaments and cells takes place at the base of the female organ as a result of this fertilization. In fact there is formed a naked cluster of spores (*c*) from these filaments, all fertilized by the single sexual act upon the central female cell.

In these few pages the endeavor has only been to point out a few of the leading methods of asexual and sexual reproduction among fresh-water algæ, and we feel in closing that the vast subject has been but here and there touched upon. But enough has been said to show that even in these lowly forms the *too often supposed* sameness of reproduction loses itself in variety of methods and multiplicity of changes.

SURFACE GEOLOGY OF THE MERRIMACK VALLEY.[1]

BY WARREN UPHAM.

THE highest fountains of Merrimack River are Eagle Lakes, on Mt. Lafayette, 1090 feet below its summit and 4170 above the sea. The source of the straight river is a lake which lies in the deep Franconia Notch, beneath the jutting rocks of the Profile. This stream is at first inclosed by high mountain ranges, and descends more than 1200 feet in its first nine miles. Distances and heights along this river are as follows: Profile Lake, about 1950 feet above the sea; mouth of East Branch, 9 miles, 710; at Plymouth, 28 miles, 468; at New Hampton, 39 miles, 438; mouth of Smith's River, two miles below Bristol, 45 miles, 320; mouth of Winnipiseogee River at Franklin, 55 miles, 269; mouth of Contoocook River at Fisherville, 66 miles, 249; mouth of Soucook River, 76 miles, 199; Amoskeag Falls at Manchester, 89 miles, 179 to 123; at line between New Hampshire and Massachusetts, 108 miles, 90; Pawtucket Falls dam, Lowell, 117 miles, 87; Essex Company's dam, Lawrence, 128 miles, 39. The entire length of this river is about 155 miles, and its last twenty miles are affected by the tide.

The Merrimack Valley in New Hampshire is comparatively straight, and forms a continuous line of depression which is a principal feature in the topography of the State. Its course is

[1] This essay is principally based upon explorations made for the Geological Survey of New Hampshire, and will be more fully presented in vol. iii. of the report on that survey.

slightly east of south. The upper and lower portions of the river which occupies this valley are known by different names. For more than fifty miles from its source, this river is called Pemigewasset; and the name Merrimack is applied to it only from the confluence of the Winnipiseogee River with the Pemigewasset at Franklin.

After entering Massachusetts the river turns to the east at North Chelmsford, and thence pursues a devious east and northeast course at right angles to its valley in New Hampshire. It here threads its way among hills, with no distinct, wide valley; and only low water-sheds divide it from adjoining basins on the south.

In considering the surface geology of Merrimack Valley, we will begin at its head and describe first the modified drift which forms conspicuous plains, terraces, and intervals or bottom-lands along its course in New Hampshire, and occurs in gravel ridges, similar to the *Kames* of Scotland, well shown at many places along the whole course of this river; next, the prominent rounded hills of coarse glacial drift or *till*, which are finely displayed along this river in Massachusetts; and, last, the marshes and beaches at its mouth. After this, we will inquire what these deposits teach in regard to the history of this valley in the glacial age, during the melting of the great northern ice-sheet, and since that time.

The modified drift of the upper part of the Merrimack, called Pemigewasset River, is usually one half mile to one mile wide, and is bordered on both sides by high hills or mountains. Below Franklin the modified drift is usually one to two miles wide; its greatest development is in Concord, in Merrimack, and in Litchfield, where it has a width of nearly four miles. The hills which border this part of the valley rise with comparatively gentle slopes, and the lowest points of its eastern water-shed are only three hundred and fifty to six hundred and fifty feet above the sea.

On Pemigewasset River modified drift occurs first in Lincoln, five miles from Profile Lake. This is very coarse, water-worn gravel, containing pebbles six inches to one and a half feet in diameter, or sometimes larger. It has an irregularly smoothed surface, imperfectly terraced, with its outer margin twenty feet above the stream. From this point modified drift is continuous on one or both sides of the river for thirty miles. In the first seven miles, to Woodstock village, it consists wholly of gravel of

different degrees of coarseness. Southward, banks and terraces of sand begin to appear, but gravel still predominates for a long distance below. The stream here frequently occupies a broad, shallow channel paved with pebbles of all sizes up to two feet in diameter, with little admixture of fine gravel or sand, which accumulates only in deep or sheltered places.

For ten miles south from the mouth of East Branch, or nearly to the south line of Thornton, a high terrace of gravel or sand is commonly well shown on both sides of the river, and has a uniform, continuous slope of fifteen feet to the mile. This slope is nearly the same as the descent of the river, which has evidently swept away this deposit to a depth of from seventy to one hundred feet over the area occupied by its channel and bordering bottom-land or interval. Nowhere else in New Hampshire is the erosion of the modified drift, by which it has been shaped in terraces, so clearly displayed. Here it seems certain that a former flood-plain, ten miles long, has been terraced as we see it by the excavation of the river.

In Campton the Pemigewasset receives two considerable tributaries from the east, Mad and Beebe rivers, which drain basins on the northwest and southeast of the mountain range that culminates in Sandwich Dome. South of the Beebe River the upper terrace, increased in height by alluvium from the tributary, forms a pine-covered plain, one mile long and a half mile wide. These "pine plains," appearing in a few places on the Pemigewasset and commonly along the Merrimack, form one of the characteristic features of this valley.

In Plymouth and Holderness both the high plain and interval are finely shown, and the extent of the alluvial area, at one point a mile and a half wide, is greater than at any other place on Pemigewasset River.

Dunes. In the north part of New Hampton and in many places for thirty miles southward to the north line of Concord, we find numerous dunes or sand-drifts lying at various heights on the east side of the valley up to three hundred feet above the highest terraces. These dunes appear in large amount and reach their greatest height near their beginning, two miles south of Ashland. Here the sand-drifts, one to five feet deep, are strewn in a pathway ten to twenty rods wide, which extends a quarter of a mile along the hill-side, with a northwest-southeast course, rising three hundred feet above the ordinary modified drift, or to a height about eight hundred and fifty feet above the sea.

These dunes occur only on the east side of the valley, consist wholly of fine sand, and lie in trains which ascend from the highest terrace in a southeast direction along the hill-side. All these characteristics indicate that they owe their origin to the transportation of sand, by the prevailing northeasterly winds, from the plains below, probably at the period when these had their greatest extent, prior to their excavation by the river, and, we may presume, before the appearance of a forest. They are usually made conspicuous at the present time by being blown in drifts, which are so constantly changing that they give no foothold to vegetation; but when they occur at considerable heights the lower portion of the series is generally grassed over, making the upper drifts appear isolated on the hill-side. The whole train of dunes before mentioned is equal by estimate to a mass one thousand feet long, fifty feet wide, and two feet deep, thus containing one hundred thousand cubic feet or five thousand tons, which has been raised by the wind an average height of one hundred and fifty feet.

Another very good illustration of this transporting power of the wind is found in Sanbornton, one mile southeast from Hill. Here, as also in New Hampton, the ancient dunes have been swept forward anew since the land was cleared. The sand from a hollow one hundred and fifty feet long, forty feet wide, and two to five feet deep has been carried, in long northwest-southeast drifts, two hundred to four hundred feet farther and twenty-five to thirty feet higher up the hill. The depth of recent excavation is shown by a large stump which has been thus undermined.

Similar dunes, high above the ordinary modified drift, occur along the east side of Connecticut River in New Hampshire and southeast from Ossipee Lake.

From New Hampton to Bristol the river flows westerly, almost at right angles with its general direction, descending by a nearly continuous slope eighty-six feet in the four miles, this being the most rapid portion of its course south of East Branch. Here it is closely bordered by sloping hills, and differs from all the rest of this valley in New Hampshire in being well-nigh destitute of modified drift. The high terraces reappear below Bristol, and thence to Franklin have a height one hundred and fifty to one hundred and seventy-five feet above the river.

From Franklin to the Massachusetts line the ancient high flood-plain of the Merrimack is everywhere well shown by conspicuous terraces. Along much of the way these terraces expand

on one or both sides into wide sandy "pine plains," so called because their principal wood-growth consists of white or pitch pines. These are often accompanied by a thick and tangled undergrowth of scrub oaks, which, with the pitch pines, flourish best on these barren plains. The terraces have a very level surface, with a regular but slight slope, which amounts to nearly the same as the descent of the river.

At Franklin the upper terrace is well defined upon both sides of the valley. It has here considerable fall in a short distance, being four hundred and forty-five and four hundred and forty feet above the sea at the north side of Webster Brook and Winnipiseogee River, and descending in less than a mile to four hundred and thirty and four hundred and twenty at their south side. In the next nine miles the upper terrace falls to a height one hundred and twenty-five feet above the river, which continues for more than twenty miles to the north part of Manchester, the highest terrace seeming to descend most rapidly near the present falls of the river, so that a nearly uniform height above the river is maintained.

In Canterbury the upper terrace spreads out into plains which are at some places a mile wide. The Boston, Concord, and Montreal railroad through this town is upon these high plains, while the Northern railroad in Boscawen and Concord lies on the lowest terrace, being embanked much of the way to raise it above the floods of spring. The plains of the south part of Canterbury, extending one mile into Concord, show an unusually rapid, continuous slope, amounting to eighty feet in four miles, or from one hundred and thirty to only fifty feet above the river. The north end of this slope appears to be at the normal height, representing the level of the river at the time of deposition of these plains, while its south end is about seventy feet below this normal line, which is here shown on the west side in the plains north and south of Fisherville.

Boscawen village is built on the south end of a similarly sloping terrace, three miles long, in which distance it falls thirty feet, and we find thirty feet more fall of the same terrace in less than a mile along the village street. The whole of this terrace is below the normal height, showing a deficiency of fifteen feet at its beginning and of forty feet at the north end of Boscawen village.

The supply of alluvium brought down by the river at this point was not sufficient to fill the valley to its average depth.

The lower portions of these slopes were probably sixty feet below the surface of water, which was held back by the extensive plains brought in from the Contoocook and Soucook valleys. These plains have their greatest development on the east side of Merrimack River, extending six miles from above East Concord to the mouth of the Soucook. Their area of greatest width, which exceeds two miles, is opposite the city of Concord.

In Boscawen and Canterbury and through Concord, the lowest terrace for twelve miles occupies a wide area, of which a large part is overflowed by the high water of spring, forming the only extensive interval on this river south of Plymouth. Fine views are here afforded at the edge of the plains, whose high bluffs descend abruptly a hundred feet, overlooking the fertile intervals and the windings of the river for miles north and south.

Ancient river-beds are indicated at many places by shallow ponds, which lie in long and frequently curved depressions of the bottom-land. Horseshoe Pond is one of these, situated at the north end of Main Street, in Concord. It is shaped like a crescent, being a half mile long, nearly as wide as the present channel, and six feet above the ordinary height of the river. Its middle portion lies at the foot of a higher terrace, against which the river once swept its full current. The nearest point of the present channel is a half mile distant at the north, where the river bends and now directs its current against Sugarball Bluff, a mile and a half northeast from Horseshoe Pond. The date of these changes cannot be stated; they occurred before the first settlement here, one hundred and fifty years ago.

On the east side of the "Fan" or broad interval opposite the north part of the city of Concord, the river formerly flowed by a very circuitous route four hundred and sixty rods, which was shortened to one hundred and fifty rods by great freshets, in 1826, 1828, and 1831, cutting a direct course across two peninsulas. Ponds occupy portions of the old channel. Sugarball Bluff, one hundred and twenty-five feet in height, which forms the edge of the sand plain near this place, is now being rapidly undermined. At Davis's Bluff, a mile to the south, and of about the same height as Sugarball Bluff, a width of three rods has been swept away in as many days. Erosion at this point has continued thirty years, requiring a dwelling-house near the edge of the bluff to be several times moved and the road changed.

These recent incursions of the river upon the plains, and the ordinary changes in its channel upon the intervals, washing away

yearly from one bank and adding to the side opposite, leave no doubt that the river has flowed at the foot of the bluffs along their whole extent, occasionally making a deep excavation beyond its usual bounds, as on the east side south of Sugarball Bluff; that the high plain originally filled the whole valley; and that the river has swept many times from side to side over the space occupied by its lower terraces and interval.

Valuable beds of clay, extensively used for brick-making, occur in the highest terrace for four miles north from Hooksett upon the east side. This clay appears to form a nearly continuous stratum, which has a thickness of twenty to thirty feet, with its top about one hundred feet above the river. It is overlaid by a few feet of sand. The upper half of this stratum consists of a hard and compact *gray clay.* At a depth of ten to fifteen feet this is frequently separated by a thin layer of sand, one fourth of an inch to three inches thick, from the underlying *blue clay*, which is soft and plastic when dug from the bank. These divisions are nearly equal in amount, but in some of the brick-yards only the upper gray clay is exposed. The same gray and blue clay, the latter always below the former, are frequently found in the southeast part of New Hampshire and along Hudson River and Lake Champlain.

At Amoskeag Falls the alluvium is two miles wide, and it averages thus for three miles below, the city of Manchester lying at the middle of this distance on the east side. The greater part of this area consists of high sandy or gravelly plains, whose barrenness made this township, under its former name of Derryfield, proverbial for poverty. The falls were then utilized only as a fishing place. The river here descends fifty-six feet, and its water-power has within fifty years built up the largest city in the State.

In Merrimack and Litchfield the high sandy plains have a larger development than in any other portion of this valley, excepting Concord. On the east side the modified drift occupies almost the entire township of Litchfield. An area one fourth to three fourths of a mile wide next to the river is the fertile low terrace, which is partly interval, as opposite the mouth of Souhegan River, but lies mostly somewhat above high water. East of this is the plain, about one hundred feet above the river, having the same height as in Merrimack on the west.

The sand and gravel of the plain between Nashua River and Salmon Brook, on which the principal part of the city of Nashua

is built, appear to have been brought partly by each of these streams and partly from the northwest along the avenue followed by the Wilton railroad, where no stream now exists. A continuous belt of alluvium, upon which this railroad is built, extends six miles from the Souhegan River in Amherst to the plains near the mouth of Nashua River. Its narrowest place, three miles from the city, is a third of a mile wide, while its widest portions, in the northwest corner of Nashua and south part of Amherst, are one and a half miles wide. These plains consist of horizontally stratified sand and gravel, and show a gradual descent from northwest to southeast, amounting to seventy-five feet in the six miles.

Kames. Remarkable ridges of coarse, water-worn gravel, frequently interstratified with layers of sand, and sometimes inclosing large, angular bowlders, occur in the Merrimack Valley in Thornton, Franklin, Boscawen, and Concord; in a series twenty miles long, which extends from Loudon along Soucook River to its mouth, and thence along the west side of Merrimack River to Manchester; in Nashua and Hudson; in another series, which has been traced by Rev. George F. Wright, of Andover, extending about twenty-five miles, through Methuen, Lawrence, Andover, Wilmington, North Reading, and Reading, to Wakefield; along Brandy Brow Brook in Haverhill, and thence continuing southward in a series similar to the last; and in Newburyport.

The plains, terraces, and intervals consist of fine gravel, sand, clay, or silt, horizontally stratified; but these ridges are mainly composed of very coarse, water-worn gravel, often containing stones two or three feet in diameter. When the gravel is mixed with layers of sand, as is frequently the case in the entire section of a ridge, these materials are very irregularly bedded, portions of them dipping at a high angle, giving the whole a rudely anticlinal or arched stratification. In many of these ridges, however, a section shows no beds of sand, and almost no marks of stratification; but there is still evidence that the deposit was formed by a current of water. It contains only the smaller bowlders which would be thus separated out from the coarse glacial drift or till; these have been more or less rounded by water-wearing, being quite different from the glaciated stones of the till, while the sand and clay have been mostly swept forward by the strength of the current. Wherever the ordinary fine alluvium has been deposited it overlies or in part covers the gravel ridges, which are therefore the oldest of our modified drift deposits. Similar

ridges of gravel have been often described by European geologists, under the various names of *kames* in Scotland, *eskers* in Ireland, and *åsar* in Sweden.

In Concord these kames form the uneven east part of Blossom Hill cemetery, and extend south one and a half miles. The south end of this series is a single steep ridge twenty-five to forty feet high, called Whale's Back, which originally extended a quarter of a mile. Its north portion has been used by the city in making and repairing streets. No kame-like deposits were discovered along the east side of the river in Concord, the whole mass of the plains being fine alluvium.

Similar ridges were next found just below the mouth of Soucook River, exposed by railroad excavation on both sides of the Merrimack. The kame here cut through by this river is a portion of a series which extends twenty miles, from Loudon to Manchester. The greater part of these kames consist of very coarse, water-worn gravel, containing pebbles six inches to two feet in diameter, with no intermixture of clear sand. They are disposed in irregular ridges of southerly trend with the valley, sometimes single, but more often with irregular branches, or several are parallel to each other. Their height varies from sixty to one hundred and twenty-five feet above the river, and they are often covered, or nearly so, by the alluvium of the plains. Upon the Soucook River these kames are repeatedly cut through by its present channel, as also near its mouth by the Merrimack, but in the fourteen miles farther south they lie wholly on the west side of the Merrimack, near the edge of its alluvial area.

This series of kames and others observed along Merrimack River in New Hampshire, the single continuous kame, one hundred and fifty to two hundred feet in height, which extends twenty-four miles along Connecticut River from Lyme, N. H., to Windsor, Vt., and a notable series which extends from Saco River at Conway to Six-Mile Pond, and from Ossipee Lake southeastward along Pine River, all lie in the middle or lowest parts of the valleys, which are bordered by high ranges of hills.

The kames which we have next to consider do not follow the present water-courses, but run directly across the Merrimack and other rivers, which here have no well-marked valleys, being not much lower than the hollows between the hills on either side. Occupying these hollows, the kames extend long distances in a somewhat devious but, for the whole series, quite straight course, which is about half-way between south and southeast.

A portion of the Andover series of kames was described by Dr. Edward Hitchcock,[1] in 1842, which appears to be the earliest notice of these peculiar gravel ridges in America. He writes: "The most common and most remarkable aspect assumed by these elevations is that of a tortuous collection of ridges and rounded and even conical hills, with corresponding depressions between them. These depressions are not valleys which might have been produced by running water, but mere holes, not unfrequently occupied by a pond."

The extent of this series was at first supposed to be about one and a half miles, but Rev. George F. Wright[2] has recently traced it fully twenty-five miles, from Methuen to Wakefield. He has also traced a second parallel series, which lies about seven miles farther east, passing through Haverhill, Groveland, Georgetown, Boxford, Topsfield, and Wenham. These ridges "are ordinarily composed of sand, gravel, and pebbles, the latter from a few inches to two or three feet through, sometimes irregularly stratified, the coarse material being as likely to abound near the top as at the bottom; at other times ten or fifteen feet or more in thickness will give no sign of stratification whatever. . . . . The fragments of rock in the ridges are nearly all somewhat rounded and apparently water-worn." The first of these series is well shown in Lawrence, a short distance southeast from the water-works reservoir. On the west side of Shawshin River, opposite Andover village, it consists of three parallel kames, known as East, Indian, and West ridges, which are respectively forty, fifty, and ninety feet high. The last two inclose a bog filled with peat and mud, twenty to thirty feet deep. The base from which these measurements were taken was forty feet above Shawshin River and ninety feet above the sea.

Prominent hills, composed of unmodified drift or till, are scattered here and there along the course of the Merrimack River through Massachusetts, and in some townships are almost as thickly set as possible. These remarkable accumulations of till are readily recognized because of their smooth and regular contour. From their resemblance in shape to a lens, Prof. C. H. Hitchcock has denominated them *lenticular hills.* They are oblong or sometimes nearly round, with steep sides and smoothly rounded tops, and vary from an eighth of a mile to a half mile in length, and from forty feet to two hundred feet in height. Their

[1] Transactions of the Association of American Geologists and Naturalists.

[2] Proceedings of the Boston Society of Natural History, vol. xix., pp. 47–63.

longest axis has most frequently a northwest-southeast trend, coinciding nearly with the course of striæ on ledges throughout this part of New England. This is well seen on the north side of the Merrimack, notably in East Kingston, Kensington, and South Hampton, N. H.; but there are many exceptions on the south side of this river.

The till on the surface of these hills is comparatively loose and sandy, brownish or yellowish in color, and contains frequent bowlders up to five feet or more in diameter, many of which are angular and wholly unworn. At a depth of two or three to fifteen or twenty feet, this *upper till* is succeeded by the very compact, clayey, and dark or bluish *lower till*, which contains few large bowlders, but is thickly filled with stones up to one or two feet in diameter, nearly all of which are glaciated, having beveled or striated sides and rounded edges.

Typical examples of these drift hills are Bear Hill in Methuen; Silver's, Golden, and Great hills in Haverhill; Morse Hill in East Kingston; Moulton Ridge, Martin, and Horse hills in Kensington; Indian Ground and Chair hills in South Hampton; Whittier's Hill in Amesbury; Powow Hill in Salisbury; Prospect Hill in Andover; Hazeltine and Dead hills in Bradford; Bald Pate Hill in Georgetown; and Crane Neck and Archelaus hills in West Newbury.

Modified drift is scanty or wanting along this part of Merrimack River. The floods from which it was deposited seem to have kept their straight course and carried the most of their alluvium southward, passing over the very low water-shed between Lowell and Massachusetts Bay. A conspicuous sand terrace at Haverhill was brought down by Little River. Its steep escarpment shows that much of this deposit has been undermined by the Merrimack.

Part of the city of Newburyport is built on a broadly rounded ridge of gravel and sand, which probably had a similar origin with the narrower and steep ridges of the kames. This deposit appears first in the south part of Amesbury. It has been cut through by Merrimack River, and on its opposite side rises to a height of about one hundred and fifty feet in Moulton's Hill. A quarter of a mile farther southeast it is depressed to seventy five feet, and shows the sharp ridges and knolls of typical kames. From this point it extends with a nearly uniform height of about one hundred feet along High Street to the middle of the city, and thence continues on the southwest side of this street to the

Upper Green. Here it is interrupted for a little distance, beyond which it lies on the northeast side of this street, extending to within a half mile of Old Town Hill. The entire length of this ridge is six miles. No other high deposits of modified drift are found in this vicinity, and wide areas of lowland border it on both sides. Excavations in the northwest part of the city show the ridge there to be composed mainly of water-worn gravel, with the largest pebbles about a foot in diameter. A railroad cut, known as March's Hill, two miles farther southeast, has only occasional layers of gravel, with the largest pebbles six inches in diameter, very irregularly interstratified with sand, which is here four fifths of the whole deposit. The depth of modified drift forming this ridge is shown by wells to be from fifty to ninety feet.

At the mouth of Merrimack River a ridge of sand, twenty-five to fifty feet high and ten to forty rods wide, extends for several miles both to the north and south, facing the ocean. Marshes a mile wide, with their surface two or three feet below the highest tides, lie on the west side of this ridge. Its gentle eastern slope forms the beaches of Salisbury and Plum Island. For a quarter of a mile or more out from these beaches the water is shallow, and the waves break upon shifting banks of sand. The ridge is built up or washed away by the same cause, and is also channeled and heaped into mounds by the winds, which are constantly changing its form.

The mouth of the river has varied much during the past sixty-five years. A fort built in 1812 at the north end of Plum Island remained at one time three fourths of a mile north from the river's mouth on Salisbury Beach. Subsequent changes have brought the river back, so that now it flows out to sea at nearly the same point as in 1812.

We having now examined the recent geological records of this valley, it remains for us to seek their order and meaning. The edges of the lenticular hills of till are overlaid by the kames, and these are in turn partly covered by the alluvium of the plains and terraces. The till is, therefore, the oldest of these deposits.

This extraordinary formation, and the rounded form and striation of exposed ledges, observed in all countries where till is found, presented one of the most difficult problems of geology, which has been solved and made clear by a theory too wonderful ever to have been conjectured, were we not led to it by abundant and undeniable testimony. This theory was first brought out prominently by Agassiz in 1840, and was based upon his studies

of the glaciers in the Alps. These fields and rivers of ice, several hundred feet in depth, are found descending from the regions of perpetual snow, their rate of motion being one to five hundred feet, or even more in their steepest portions, in a year. Many angular blocks and fragments which fall from the bordering cliffs are carried along on the surface of the ice, or are contained in its mass, with others torn from the rocks over which it moves, and under its vast weight these act as graving tools to round and striate the ledges beneath. The similar striation of all northern countries and the formation of the till have been effected by a uniform cause, namely, a moving ice-sheet which overspread the continents from the north.

This continental glacier had accumulated sufficiently deep to cover every mountain summit in New Hampshire. That it overtopped Mt. Washington is fully proved by recent discoveries of Professor C. H. Hitchcock, the state geologist. Its thickness farther to the north was so much greater than in this latitude that its immense weight caused the ice to flow slowly outward, and the direction of its current in New England was to the south and southeast. By this motion fragments were torn from the ledges, and a large part of these were sooner or later held in the bottom of the ice and worn to a small size by friction upon the surface over which it moved. The resulting mixture formed beneath the ice is the ground-moraine or *lower till.* Its dark and frequently bluish color is due to seclusion from air and water during its formation, as pointed out by Torell, leaving its iron principally in the form of ferrous silicates or carbonates ; and its compactness and hardness have resulted from compression under the great weight of ice. While this deposit was thus accumulating beneath the ice, great amounts of material, coarse and fine, were swept away from hill slopes and mountain sides, and afterward carried forward in the ice. When this melted a large portion of the material which it contained fell loosely upon the surface, forming an unstratified deposit of gravelly earth and bowlders, called *upper till.* It will be seen that the upper member is the one usually exposed at the surface, and it is often the only one present where only a thin covering of till is found. Its characteristics are the larger size of its bowlders, which are mostly angular and unworn ; the yellowish color of its fine detritus, produced by the hydrated ferric oxide to which its iron has been changed by exposure to air and water ; and the comparative looseness of its whole mass.

Frequently about Winnipiseogee Lake, and rarely elsewhere, de-

posits of stratified clay or sand are found between the lower and upper till. In these places the contour of the land seems to have prevented free drainage from the foot of the melting ice-sheet. The water then melted large open spaces beneath the ice near its margin, in which these beds of stratified drift were deposited. The overlying till was contained in the ice-sheet, and fell upon the surface when its melting was completed.

The distribution of the till in this valley is quite irregular. Sometimes no considerable accumulations of it are seen for several miles, and the ledges lie at or near the surface. Elsewhere the till occurs in large amount, covering the ledges which are scarcely exposed over some whole townships near the coast. Wherever it is found plentifully it is to a large extent massed in the peculiar lenticular hills, which, except a thin layer on the surface, are entirely composed of lower till; but we cannot explain how the ice acted to accumulate its ground-moraine over some sections in these regular hills, while over other large areas, apparently not otherwise different, they are wholly wanting.

The departure of the ice-sheet was attended with a comparatively rapid deposition of the abundant materials which it contained. It is probable that its final melting took place mostly upon the surface, so that at the last great amounts of detritus were exposed to the washing of its innumerable streams. The surface of the ice-sheet became molded by this process of destruction into great basins and valleys, and the avenues by which its melting waters escaped came gradually to coincide with the depressions of our present surface. When the glacial river entered the open area from which the ice had retreated, or in the lower part of its channel while still walled on both sides by ice, its current was slackened by the less rapid descent, causing the deposition first of its coarsest gravel, and afterwards, in succession, of its finer gravel, sand, and fine silt or clay. The valleys were thus filled with extensive and thick deposits of modified drift, which increased in depth in the same way that additions are now made to the bottom-lands or intervals of our large rivers by the annual floods of spring. The portion of the material contained in the ice-sheet which escaped this erosion of its streams formed the upper till. The abundant deposition of drift, both stratified and unstratified, during this final melting of the ice-sheet has been brought into its due prominence by Prof. James D. Dana, who denominates this the *Champlain period*, deriving the name from marine beds of this era which occur on the borders of Lake Champlain.

The oldest of our deposits of modified drift are the *kames.* From the position of these peculiar accumulations of gravel, which are overlaid by the horizontally stratified drift, the date of their formation is known to be between the period when the ice-sheet moved over the land and that closely following, in which this more recent modified drift was deposited in the open valleys from the floods that were supplied by the melting ice. We are thus led to an explanation of the kames which seems to be supported by all the facts observed in New Hampshire and Massachusetts, and which appears to apply also to the similar deposits that have been described in other parts of the United States and in Europe.

The melting of the ice-sheet over New England advanced from the sea-coast towards the north and northwest. The lowest and warmest portions of the land were probably first uncovered, and as the melted area advanced into the continental glacier its vast floods found their outlet at the head of the advancing valley. This often took place by a single channel bordered by ice-walls, as was the case along the Connecticut kame; but in the Merrimack Valley and in Eastern Massachusetts, these glacial rivers also frequently had their mouths by numerous channels, which were separated by ridges of ice. In these channels were deposited materials gathered by the streams from the melting glacier. By the low water of winter layers of sand would be formed, and by the strong currents of summer layers of gravel, often very coarse, which would be irregularly bedded, — here sand and there gravel accumulating, and, without much order, interstratified with each other. Sometimes the melting may have been so rapid that the entire section of a kame may show only the deposition of a single summer, which would then be very coarse gravel without layers of sand. When the bordering and separating ice-walls disappeared, these deposits remained in the long ridges of the kames, with steep slopes and irregularly arched stratification. Very irregular short ridges, mounds, and inclosed hollows resulted from deposition among irregular masses of ice. The *glacial rivers* which we have described appear to have flowed in channels upon the surface of the ice, and the formation of the kames took place at or near their mouths, advancing as fast as the ice-front retreated.

The extensive level *plains and high terraces* which border our rivers, constituting the most conspicuous and by far the largest portion of our modified drift, were also deposited in the Champlain period. The departing ice-sheet was the principal source

both of the vast amount of material and of water for sweeping it into the valleys, which appear in most cases to have been thus filled to the level of their highest terraces. The prevailing horizontal stratification of these deposits shows that they were spread over large areas by the current of the floods which held them in suspension. The modified drift thus increased in depth in the principal valleys through a long period, which may have continued till the last of the ice at the heads of the valley and of its tributaries had disappeared.

During the recent or *terrace period* the rivers have been at work excavating deep and wide channels in this alluvium. The terraces mark heights at which in this work of erosion they have left portions of their successive flood-plains. As soon as the supply of material became insufficient to fill the place of that excavated by the river, a deep channel was gradually formed in the broad flood-plain. This process was very slow, allowing the river to continue for a long time at nearly the same level, undermining and wearing away its bank on one side, and depositing the material on the opposite side, till a wide and nearly level lower flood-plain would be formed, bordered on both sides by steep terraces. When the current became turned to wear away the bank in the opposite direction, a large portion of this new flood-plain would be undermined and redeposited at a lower level; but the direction of the current's wear might be again reversed in season to leave a narrow strip which would then form a lower terrace. In this way the Merrimack River through New Hampshire has excavated its ancient high flood-plain of the Champlain period to a depth of seventy-five to one hundred and fifty feet, for a width varying from an eighth of a mile to one mile. In Canterbury and Concord we see the highest plain is being now undermined by the wear of the current, forming steep bluffs.

The very fine character of the materials which compose the lowest terraces and the interval or present flood-plain is due to this wearing away and redeposition by the river, which have been many times repeated, till what may have been at first gravel becomes very fine sand or silt. By each removal this alluvium is made one degree finer, and is deposited at a lower level and farther down the stream. The end of its slow journey is the ocean, where it will help to make the sedimentary rocks of this epoch. It has completed a great cycle of changes, ending where the upheaved and contorted ledges from which it was derived had their remote beginning.